# Integrated Fitness-for-service Program for Natural Gas Transmission Pipeline

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# 천연가스 공급배관의 사용적합성 통합프로그램

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## Abstract

For fitness-for-service analyses of underground natural gas pipelines, engineering assessment methods against possible defects need to be developed. The assessment methods for high pressure pipeline of KOGAS, was developed using the full size pipe burst tests and the finite element analysis. It included the defect assessment methods for a single and multi-corrosion, corrosion in girth welding part, corrosion in seam welding part, the mechanical damage defects as dent and gouge, crack and large plastic deformation of API 5L X65 pipe. In addition, we developed method to assess pipeline integrity by internal and external load to buried pipeline. Evaluation results were compared with other methods currently being applied to the gas pipeline.

The program of Windows environment is made for easily using assessment methods. It provides a consistent user interface, so non-professional technician can easily and friendly use the FFS program from company intranet. Several evaluation programs is easily installed using one installer. Each program constitutes a common input interface and the output configuration program, and evaluation result store and can be recalled at any time. The FFS program based on independent evaluation method is used to evaluate the integrity and safety of KOGAS pipeline, and greatly contribute to safe and efficient operation of pipeline.

This paper presents experimental, analytical and numerical investigations to develop the FFS methods for KOGAS pipeline, used as high pressure natural gas transmission pipeline within KOREA. Also, it includes the description of the integrated program for FFS methods.

## 1. Introduction

To assess the integrity of the pipeline is the most important problem to be solved first of all for prevention of any fracture accident of the pipeline, which has continued to be a study subject since 1980's. As a result of exerting such efforts, a criterion of assessing defects in the form of fitness for service (FFS) based on the engineering critical analysis (ECA) has been suggested, and on the basis of it, assessment of the integrity of the pipeline with any defect detected through the non-destructive test, etc. has been under way.

Also, such codes as API RP 579[1], BS 7910[2], R6[3], etc. are widely used for analysis of the fracture behavior of the pipeline. Since these guidelines do not give usage and application limits, there may be some limitations in applying the guideline to domestic gas pipeline in Korea. So, KOGAS (Korea Gas Corporation) began constructing its own FFS code appropriate to the situations of

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KOGAS pipeline.

The failure assessment for the defects in damaged pipeline has been considered with the full size pipe burst tests and the associated finite element method. The damaged pipe made of API 5L X65, which used as the main natural gas transmission pipeline in Korea, has been used for a number of series of burst tests with various types of artificially machined defects with respect to each designed defect sizes – length, width and depth. The result from the experiments has been modeled and compared with finite element method. The assessment methods for each defects have been derived from FEM simulation and mechanical test result.

In this paper, KOGAS FFS code and integrated FFS program are described. The main contents include: (1) the defect assessment method for various corrosions, gouge, crack, plastic collapse (2) the consideration for the situations of KOGAS pipeline, and (3) the development of user-friendly program.

## 2 Defect assessment method and integrated program of gas ipeline

### 2.1 Corrosion defect

1) Single and multi corrosion defect assessment [4-5]

On comparison with experimental test result, estimation of PCORRC equation (1) proved to be conservative and the closest when using 95% of $\sigma_{u,Test}$ as $\sigma_u$ .

$$P_{burst} = \sigma_u \frac{2t}{D}\left(1 - \frac{d}{t}\left(1 - \exp\left(-0.157\frac{L}{\sqrt{Rt^*}}\right)\right)\right) \quad (1)$$

Where, $P_{dl}$ is the burst pressure, $\sigma_u$ is the ultimate tensile stress, t is the wall thickness od pipe, D is the diameter of pipe, d is the maximum depth of defect, L is the axial length of defect, R is the radius of pipe, and t* is the remaining ligament wall thickness in the defect (=t-d).

The burst pressure of damaged pipe of API 5L X65 with a same equation has been used as such,

$$P_d = 0.95\sigma_{u,Test}\frac{2t}{D}\left(1 - \frac{d}{t}\left(1 - \exp\left(-C\frac{L}{\sqrt{Rt^*}}\right)\right)\right) \quad (2)$$

where, C is the curve fit constant.

When pit depth is constant, behavior of burst pressure with increasing defect length(L) can generate C value by fitting procedure. The resulted C value varies from 0.142~0.224 with the change of pit depth. However for conservative pridiction of damaged pipe, we can choose maximul value of 0.224 as curve fit constant for whole range of depth. Then, limit solution about single pit model is as follows.

$$P_d = 0.95\sigma_{u,Test}\frac{2t}{D}\left(1 - \frac{d}{t}\left(1 - \exp\left(-0.224\frac{L}{\sqrt{Rt^*}}\right)\right)\right) \quad (3)$$

Figure 1 is compared with experimental result of equation (3), which shows good agreement with experimental result and conservative on whole range of length increases.

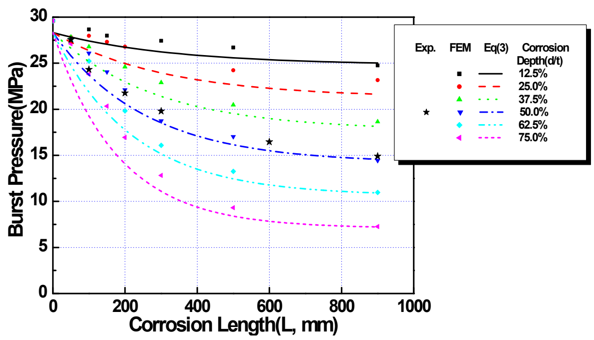



Figure 1 The comparison of experimental result, FEA result and calculated burst pressure by Eq. (3).

For multiple pit model, a equation for capture the global behavior of longitudinally aligned two pits has been derived. For two longitudinally aligned two pits having length L, as distance between two pits is too small, it would acts as a single pit of length 2L. While the distance between two pits is too large, it would act as a single pit of length L. The relationship of burst pressure may be expressed fitting procedure of FE simulation result. To include single result of length L and 2L, parameter of distance between two pits is changed as follows,

$$sl' = \frac{sl}{sl + a} \quad (4)$$

where sl' is re-defined distance between two pits. And a means a constant to normalize sl'. When sl'=0, distance of multiple pits is zero, so the burst pressure can be replaced with a single defect having distance of 2L, on the contrary, sl'=1, multiple pits model considered having unlimited distance.

If relationship of burst pressure change due to superposition of stress between pits and distance between two pits expressed as f(sl'), burst pressure of two pits model can be expressed as follows,

$$P_{d,Multi} = f(sl')(P_{d,L} - P_{d,2L}) + P_{d,L} \quad (5)$$

where, $P_{d,L}, P_{d,2L}$ means burst pressure of single pit model of length L, and length 2L, respectively. By fitting procedure of FE simulation result, f(sl') can be expressed ,

$$f(sl') = 1 - Exp(-sl'/t_1) \quad (6)$$

The behavior of longitudinally aligned pit model is derived as follows,

$$P_{d,Multi} = (1 - Exp(-sl'/t_1))(P_{d.L} - P_{d,2L}) + P_{d,L} \quad (7)$$

2) **Corrosion defect assessment method in weld parts** [6]

Full scale burst tests and FEA was carried out to evaluate the burst pressure of corrosion defect within the girth weld and the seam weld. On the comparison of experimental results, the burst pressure of corrosion defects within the girth weld and the seam weld was higher than that of within the body of pipe. However, on the comparison of FEA results, although the burst pressure of corrosion defect within girth weld was slightly higher than that of within the body of pipe, the burst pressure of corrosion defect within seam weld was slightly less than that of corrosion defect within the body of pipe. The reason for low burst pressure of corrosion defects within seam weld was considered that the stress concentrated at the HAZ of seam weld due to geometrical shape and the ultimate tensile strength of the HAZ of seam weld was less than that of the body of the pipe.

In order to develop a conservative assessment, the assessment criterion of corrosion defect within the girth weld is identical with that of within the body of pipe.

$$P_{f,GirthWeld} = P_{f,Body} = 0.95\sigma_{UTS,True}\frac{2t}{D}\left[1 - \frac{d}{t}\left\langle 1 - \exp\left(-\frac{0.224L}{\sqrt{R(t-d)}}\right)\right\rangle\right] \quad (8)$$

The estimated burst pressure of FEA result for corrosion defects within the seam weld was higher than calculated burst pressure with 0.9 times Eq. (3). In order to develop a conservative assessment, the assessment criterion of corrosion defect within the seam weld is identical with 0.9 times Eq. (3).

$$P_{f,SeamWeld} = 0.9 \times P_{f,Body} = 0.86\sigma_{UTS,True}\frac{2t}{D}\left[1 - \frac{d}{t}\left\langle 1 - \exp\left(-\frac{0.224L}{\sqrt{R(t-d)}}\right)\right\rangle\right] \quad (9)$$

## 2.2. Gouge Assessment [7]

A comparison of the results using ASME B31, PCORR, formula suggested by Kiefner indicates. Burst pressure of gouge defect pipe piping similarly showed up corroded pipe,

Since gouge has notch shape, causing a high stress concentration in the center of notch, burst pressure will have lower than the single corrosion. However, because the gas pipeline material is excellent toughness, burst pressure of gouge pipe did not appear greatly reduced of compared with the corrosion of smooth defect. And the Kiefner's assessment method depending on flow stress predicts more conservative burst pressure than the experimental results.

All of the actual burst pressure of gouge pipe is higher than predicted values based on PCORRC, but PCORRC assessment method relatively accurately predict the burst pressure. In terms of safety, if selected more conservative assessment method than the actual, it is appropriate that PCORRC assessment method for gouge pipe used as the base.

As shown in Figure 2, the burst pressure of gouge pipe with change of the length and depth predicted using FEA and performed the fittings to connect the each result.

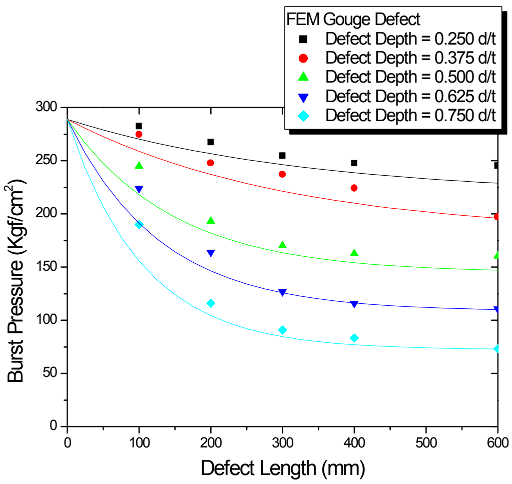



Figure 2 FEM and fitting result of gouge defect

To represent the conservative in full interpretation of values, the constant value represents the largest segment in every decision of value. The assessment criterion of gouge defect can be expressed as follows.

$$P_{burst,Gouge} = 0.95\frac{2t}{D}\sigma_{ult}\left(1-\frac{d}{t}\left(1-\exp\left(-C_2\frac{L}{\sqrt{R(t-d)}}\right)\right)\right)$$
$$C_2 = 0.191(d \le 0.375t)$$
$$C_2 = 0.396(d > 0.375t) \qquad (10)$$

The burst pressures to calculate by this formula represent better trends of results change of FEA and full scale pipe test, and include a little conservative.

## 2.3. Crack type defect assessment [8]

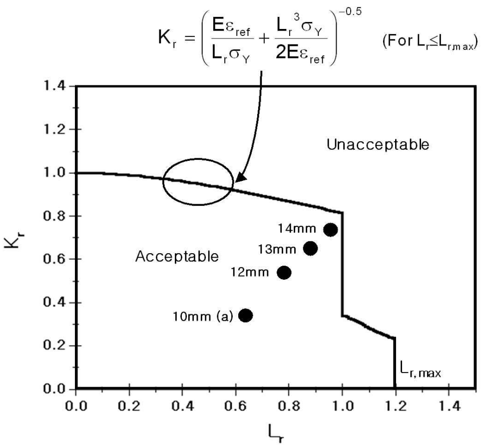
FFS assessment was performed for longitudinal surface flaws existing in natural gas pipeline weldments using the tensile properties and fracture toughness values. Only internal pressure was assumed as an applied force, since this is the dominant force on the pipeline. Since hoop stress due to internal pressure is twice as large in pipelines as axial stress, a longitudinal crack was selected as the target flaw.

In the FAD for weld metal, the material properties of the seam weldment, which is parallel to the crack direction, were used to plot the assessment point. The level-1 FAD indicates that the weld metal is more susceptible to elastic fracture than base metal and that the base metal is more susceptible to plastic collapse than the weld metal.

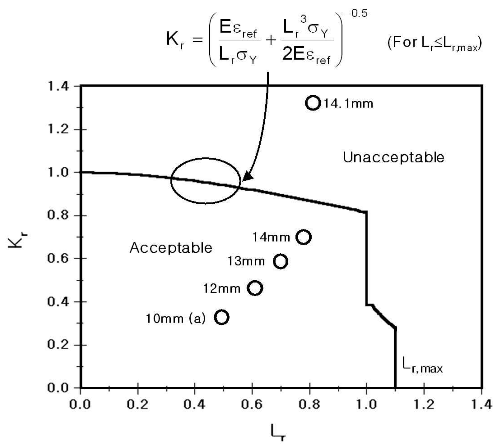
The unacceptable cracks in level-1 FAD must be reassessed in a level-2 FAD. As for level 1, the tensile properties and fracture toughness proper to crack locations were used to construct this level-2 FAD.

To assess FFS more accurately, the above cracks were assessed in a level-3 FAD (Figure 3). Since the level-3 FAC includes tensile properties as a variable, the FAD for base metal differs from that for weld metal. In the FAD for base metal (Fig. 3a), since the assessment point of the 14-mm crack was located inside the FAC, the crack was acceptable, and the pipeline with this crack can be used without repair. But the FAD for the weld metal (Fig. 3b) shows that the 14.1-mm crack is unacceptable even in level 3 and that repair or replacement with fresh material is required.

Crack assessment results can be strongly affected by crack location, i.e. the representative mechanical properties of the regions containing cracks. Thus a crack within the HAZ produces quite different results from the results according to current FAD codes, which suggest that weld-metal properties instead of HAZ properties can be used for flaws in the HAZ. We constructed a HAZ-focused FAD using lower-bound HAZ properties from microtensile tests and HAZ-notched CTOD tests. The HAZ-focused FAD differs from the current-code FAD in two respects. First, the FAC for the HAZ does not overlap the FAC for weld metal. Second, the assessment points (Lr, Kr) for the weldmetal and HAZ are not the same.




(a)



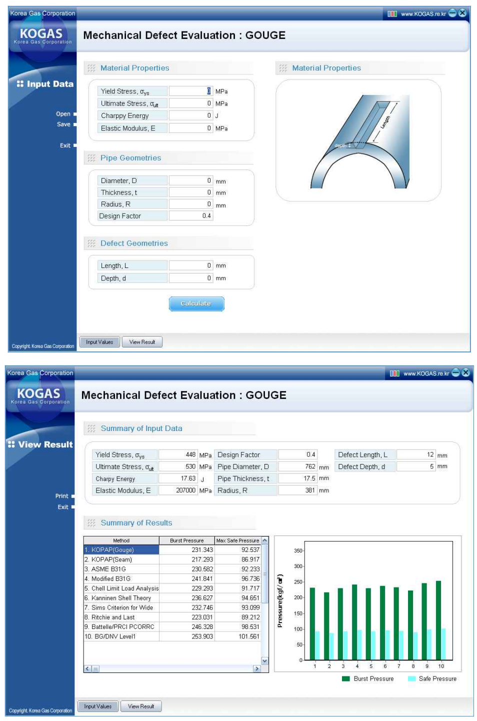

(b)

Figure 3 Level-3 FAD for (a) base metal and (b) weld metal.

## 3. Integrated FFS Program

The pipeline integrity assessment system of the Windows environment is easy to use, so that would maximize effect of the research result performed by Korea Gas Corporation, R&D Center. KOGAS FFS program include the assessment methods for corrosion defect (single, multi, girth weld, seam weld), mechanical damage (Gouge, Dent), crack type defect, buried pipe safety, plastic collapse.

The key features of program are as follows. User can easily perform the program by providing a consistent user interface. To perform one INSTALLER install easy multiple evaluation program. Each program will enter a common interface to configure the program and calculation program output. The evaluation is performed to save and can be reused at any time. Each assessment program divided data input, FFS analysis and result output. In the part of the interpretation of results, each evaluation results can be revalued the resulting change depending on the desired assessment Variable. Figure 4 represents the program assessment procedure of gouge defect.



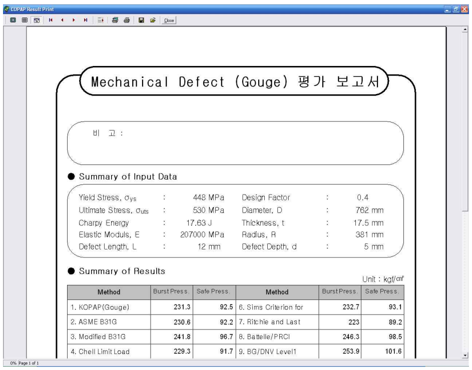



Figure 4 Program assessment procedures of gouge defect

## 4. SUMMARY

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## 5. References

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